Neutrino Factory Designs and R&D

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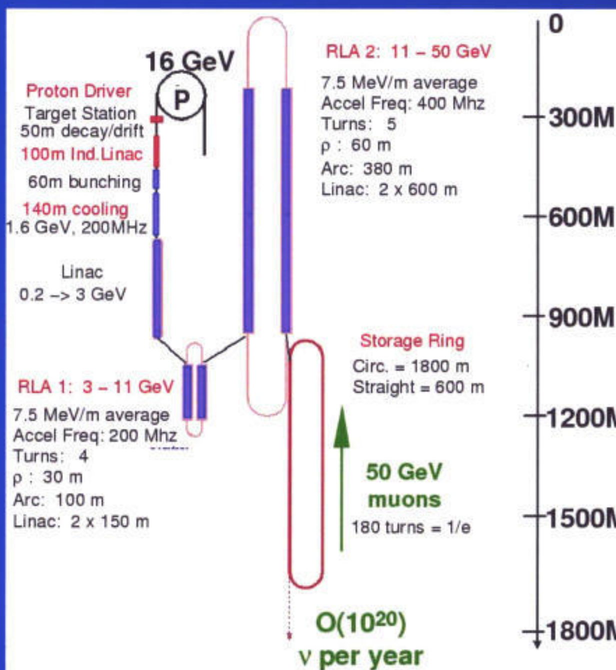
Fermilab

Introduction

- In recent years there has been significant interest in a new type of muon source >> a millimole of muons per year originally motivated by interest in Muon Colliders
- Neutrino Factory design concepts emerged in 1997-98 … based on exploiting a muon collider like muon source.
- Since then: 2 design studies in US, one in Europe & alternative design concept developing in Japan → Neutrino Factories feasible, but require hardware R&D.
- Will summarize the Neutrino Factory design options and progress with the hardware R&D

US ν-Factory Scheme



Design Study 1 (completed April 2000)

Proton driver: Upgraded FNAL Booster

Carbon target in 20T capture solenoid

50m decay channel (1.25T)

Muon energy spread reduced using induction linac (phase rotation)

Muons bunched at 200 MHz

Transverse phase space reduced using an ionization cooling channel

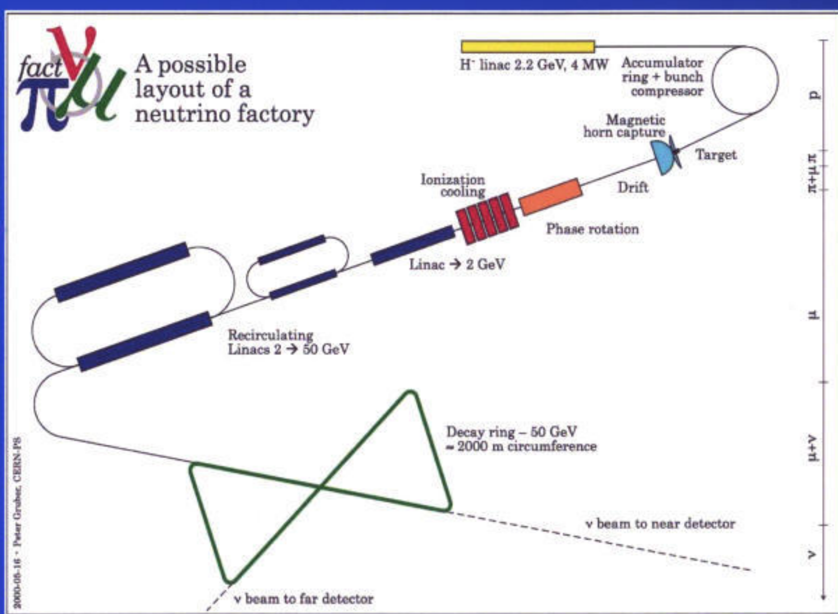
Acceleration to 50 GeV in RLAs

Design Study 2 (completed May 2001, based on upgraded BNL AGS)

Hg jet target, better induction linac & cooling channel designs

Achieved 6 x Study 1 muon rate >> 2 E20 useful μ decays / year

CERN ν-Factory Scheme



Similar to US scheme but alternative technologies:

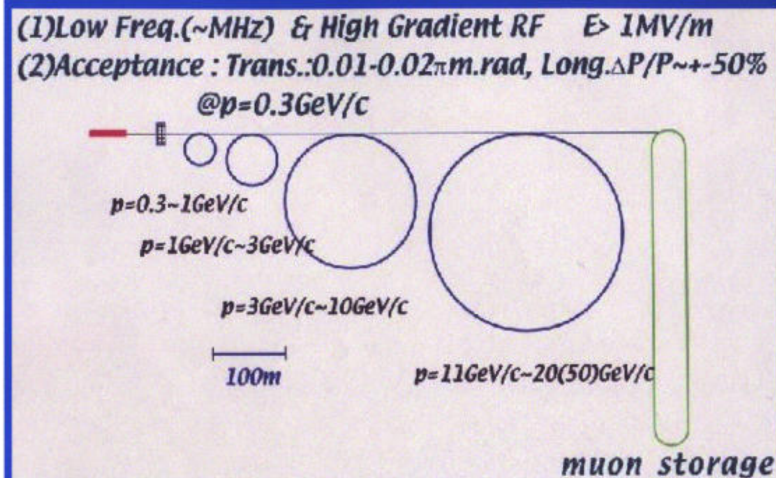
Lower energy proton driver (2.2 GeV protons)

Pion capture with magnetic horn

RF for phase rotation (no induction linac)

Transverse cooling channel With 44/88 MHz (not 200 MHz) RF cavities.

Japanese ν-Factory Scheme



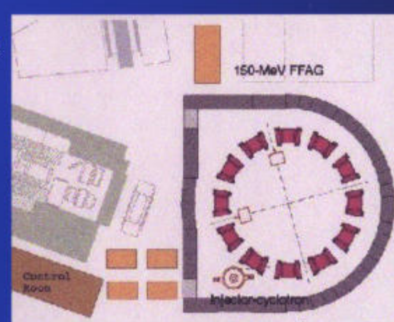
NO PHASE ROTATION OR COOLING
(would benefit from some cooling)

USE LARGE ACCEPTANCE ACCELERATORS - FFAGs

R&D Issues: RF, Injection/extraction, magnet design, dynamic aperture

GOAL: 1.E20 >> 4.4E20 USEFUL muon DECAYS / YEAR @ 20 GeV >> 50 GeV

Proof of Principle (POP) FFAG tested at KEK in June 2000



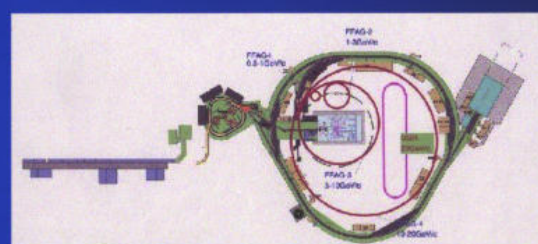
NEXT STEP
150 MeV FFAG
Under construction
At KEK

RF R&D: US/Japan collaboration

Proton Sources

- The starting point – a multi-GeV proton source providing an O(1 MW) beam on target. **Everyone has a viable scheme:**

CERN: 2 GeV SPL – 4MW



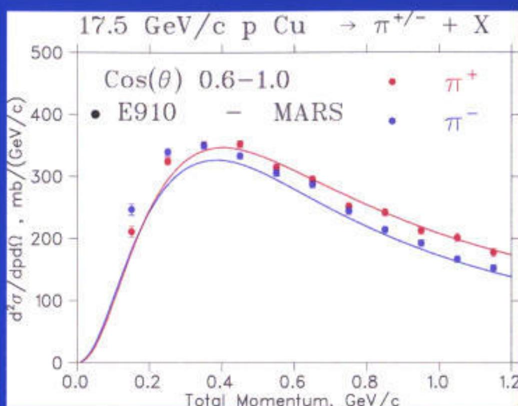
Japan: 50 GeV, 0.8 MW JHF
(upgrade to 4MW)

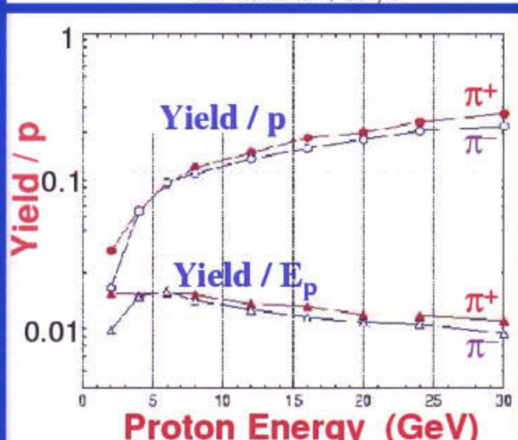
BNL: Upgraded AGS
24 GeV, 1-4 MW

FNAL: Upgrade d Booster
8-16 GeV, 1-4MW

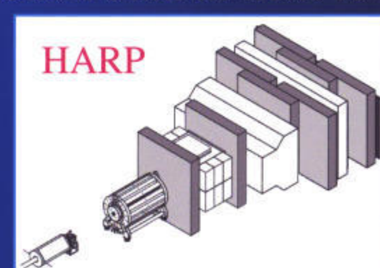
NEUTRINO FACTORIES FIT ON EXISTING SITES & CAN USE UPGRADED EXISTING PROTON DRIVERS >> PLENTY OF CANDIDATE SITES

Producing Pions



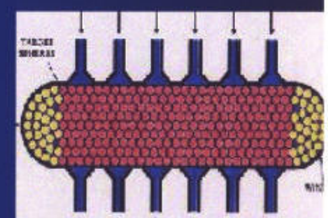


- NEW BNL E910 pion production Results
  - Pion yields peak at few hundred MeV/c
  - Data in fair agreement with MARS predictions (yields may be slightly higher than predicted)
- At constant proton beam power, pion yields vary slowly with proton energy >> broad range of proton driver energies can be considered.
- More particle production data in next few years from:
  - HARP (CERN)
  - Fermilab E907

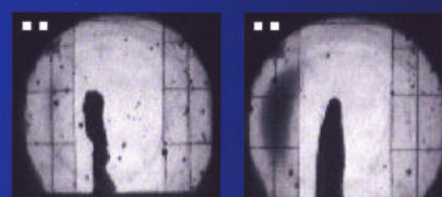


Target R&D for MW-Scale Proton Beams

- Carbon Target tested at AGS (24 GeV, 5E12 ppp, 100ns)
  - Probably OK for 1.5 MW beam … limitation: target evaporation
- Target ideas for 4 MW: Water cooled Ta Spheres (P. Sievers), rotating band (B. King), conducting target, Front-runner = Hg jet

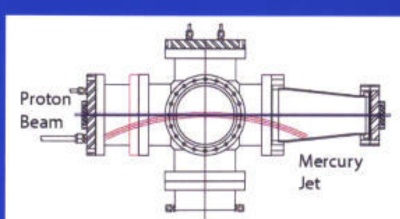


- CERN/Grenoble Liquid Hg jet tests in 13 T solenoid
  - Field damps surface tension waves

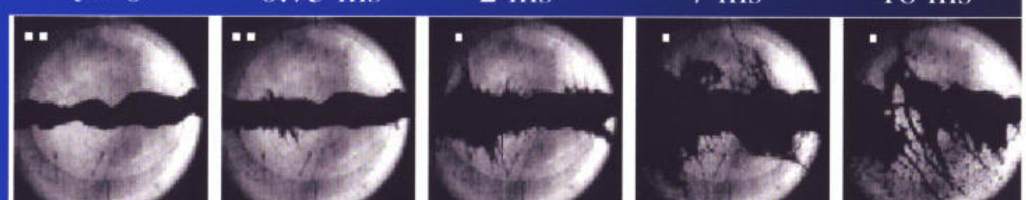


0 Tesla 13 Tesla

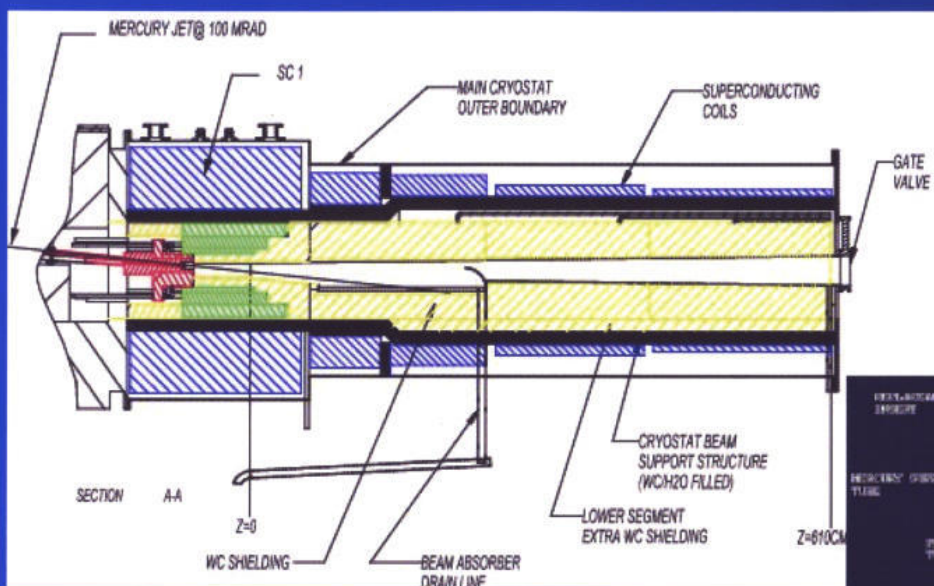
- BNL E951: Hg Jet in AGS beam
  - Jet (2.5 m/s) quickly re-establishes itself. Will test in 20T solenoid in future.

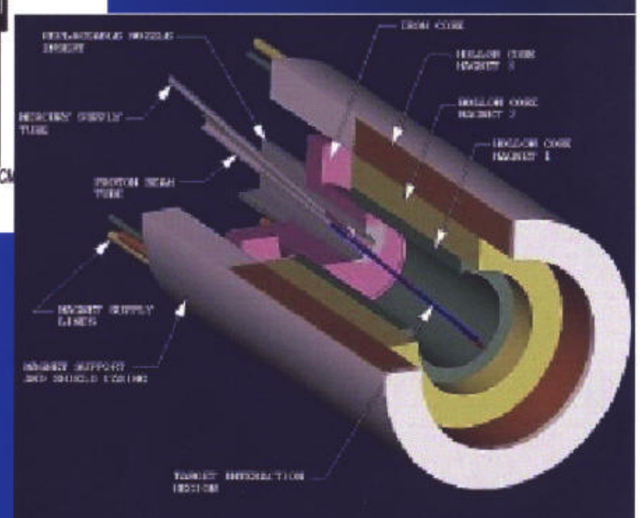


t = 0 0.75 ms 2 ms 7 ms 18 ms



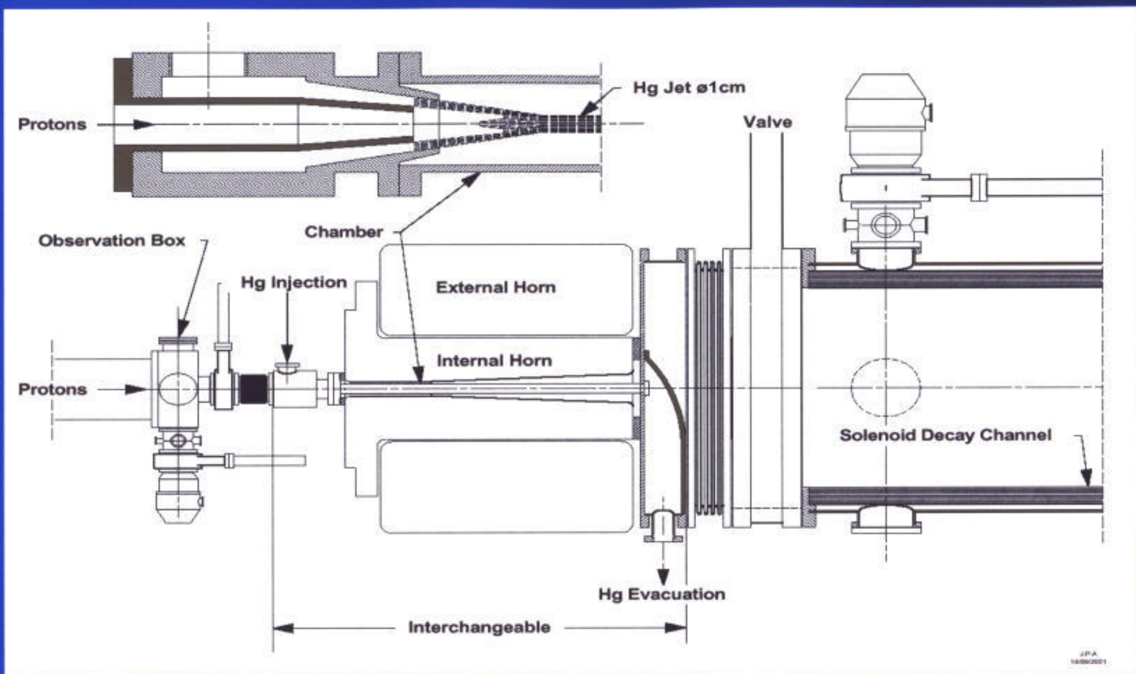
Pion Capture - 1





US Design: Target in ~20T capture solenoid which tapers down to 1.25T

Pion Capture - 2

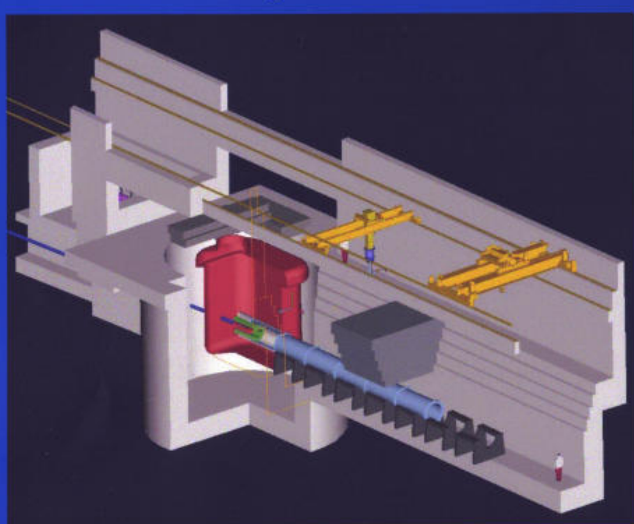


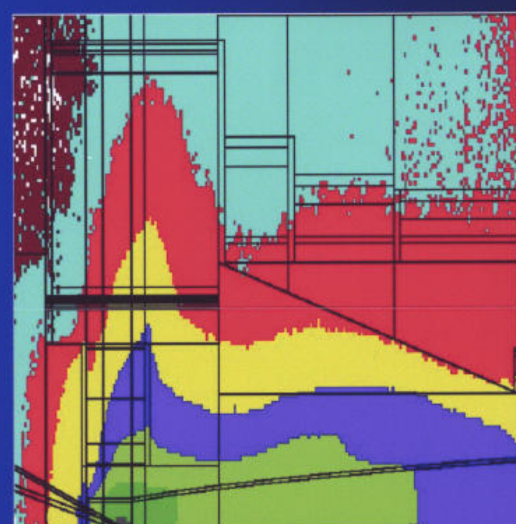
CERN Design: Use 50 Hz magnetic horn
(waist radius = 4 cm, I = 300 kA)

Test horn (low current & rep. rate) almost completed → mechanical behavior

Target Facility

Need remote handling target facility – detailed design made for US neutrino factory studies 1 and 2.

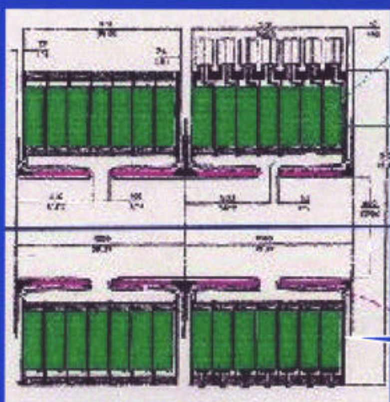




Based on SNS (Oak Ridge) design experience.

Detailed radiation simulations (MARS, N. Mokhov) >> facility lifetime OK

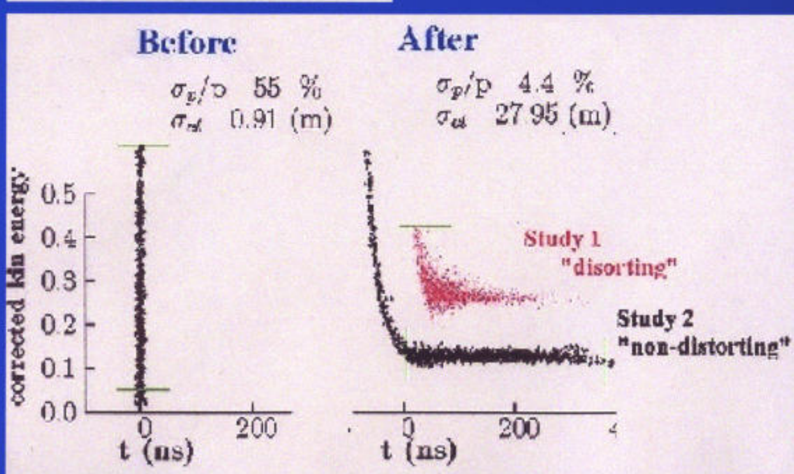
Reducing the μ Energy Spread

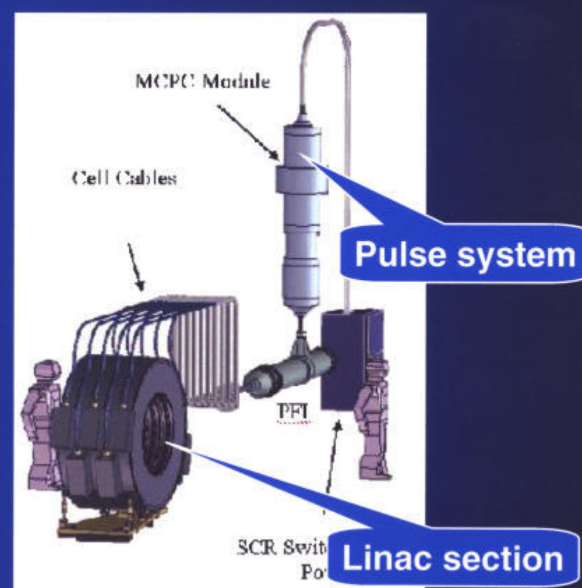


PHASE ROTATION: Drift followed by a time-dependent Acceleration (fast particles de-accelerated, slow accelerated)

US Scheme: use 260m long (r = 95 cm) Induction Linac with internal 1.25T solenoid: $\sigma(p)/p = 55\% >> 4.4\%$

2 m Section





Reducing the Transverse Phase Space

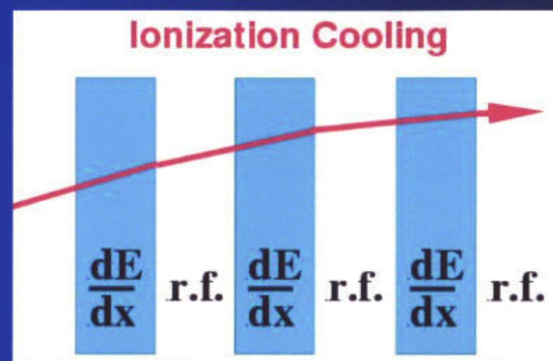
Transverse phase space too large to fit within normal accelerator

Must "cool" the beam fast – Before muons decay

Electron cooling & stochastic Cooling too slow
>> USE IONIZATION COOLING

An ionization cooling channel Can be thought of as a LINAC Filled with material

Need high gradient RF to keep the muons captured



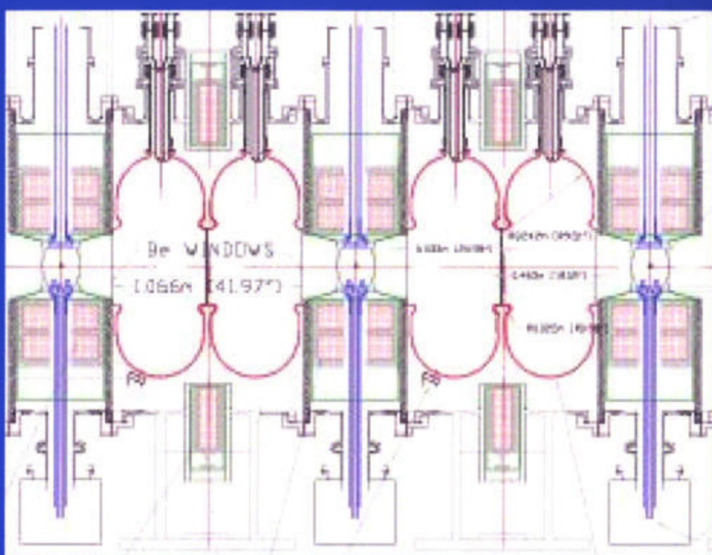
Coulomb scattering tries to heat beam

Use Liquid Hydrogen absorbers

Use strong radial focusing
>> high field solenoid channel

Cooling Channel Design

3.3 m long section



Liq. H RF Liq. H RF Liq. H

21 cm long Liquid hydrogen absorbers in high-field solenoid with field reversing direction at absorber

Study 2 Design (R. Palmer)

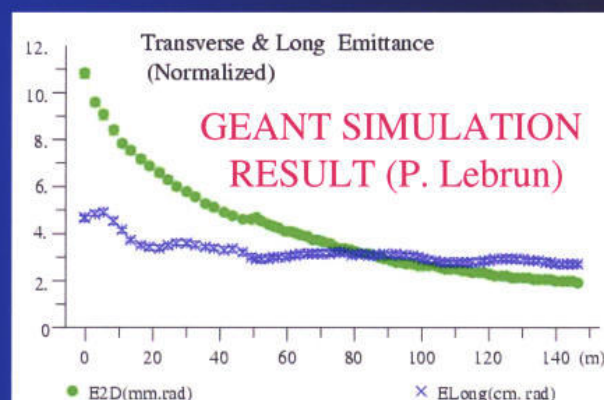
Channel Length: 108 m

Lattice period: 5.4 m >> 3.3 m

High field solenoid : 3T >> 5T

Solenoid radius: 33 cm >> 20 cm

RF: 17 MV/m @ 200 MHz



MUCOOL RF R&D

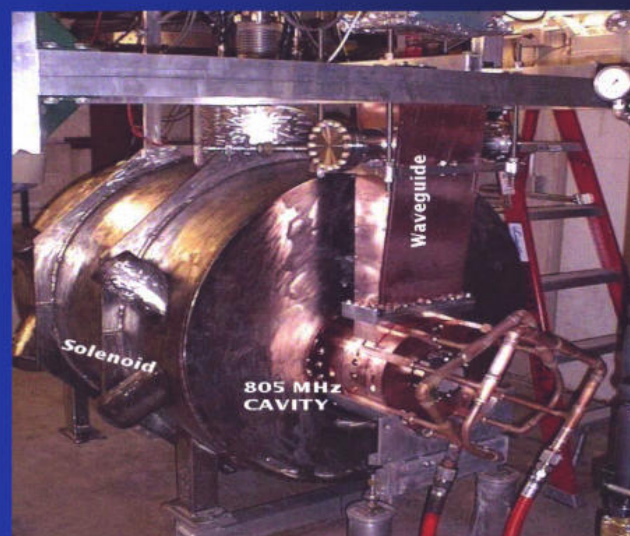
Need high gradient cavities in multi-Tesla solenoid field

Concept 1 – open cell cavity with high surface field

805 MHz Cavity built & tested
→Surface fileds 53 MV/m achieved
→Large dark currents observed
→Breakdown damage at highest gradients
→Lots of ideas for improvement

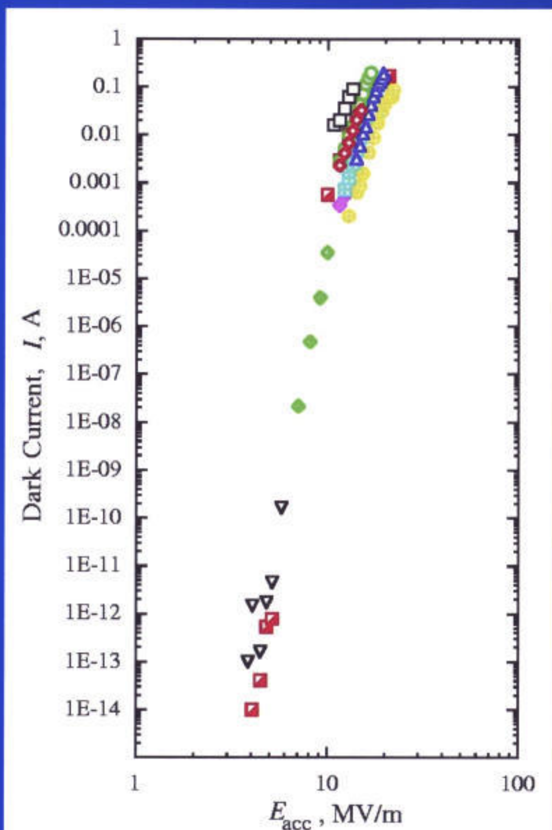
Concept 2 – pillbox cavity - close aperture with thin conducting foil

805 MHz Cavity built & being tested



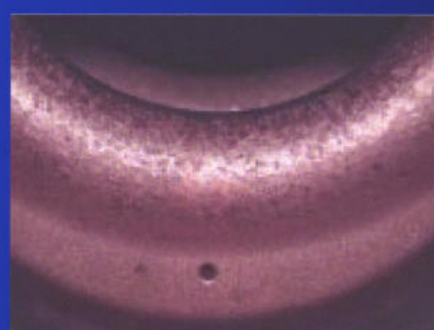
High Power 805 MHz Test Facility
12 MW klystron
Linac-type modulator & controls
X-Ray cavern
5T two-coil SC Solenoid
Dark-current & X-Ray instrumentation

MUCOOL Open Cell Test Results



Dark currents increase with accelerating filed 10 the 10th – 15th power – understood within the framework of Fowler Nordheim field emission

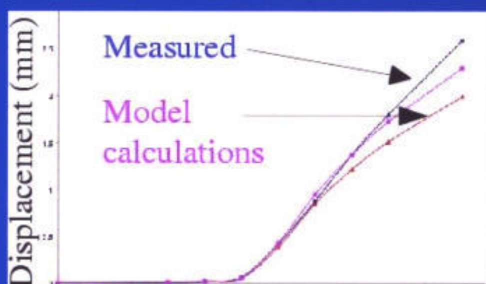
Cavity operated successfully at full power with B = 0T, and 2.0T. Cavity damage stopped operation at 2.5T.

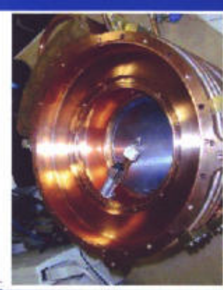


R&D to improve surface quality, reduce dark current, suppress breakdown planned & beginning

Iris damage at high gradients

MUCOOL Pillbox Cavity Results



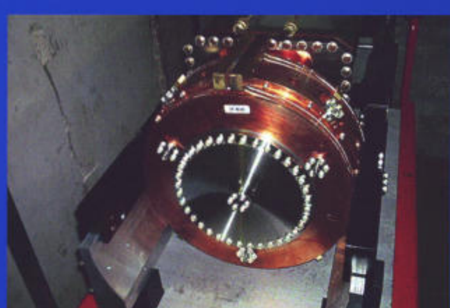


Window Displacement vs Power dissipated

Close aperture with conducting foil/grid (at fixed peak power this doubles gradient)

Initial R&D with Be windows

Window deflection as it heats up measured & understood



High power test cavity built (LBNL, Mississippi)

Operated at full power with copper foil and B = 0

To be tested in multi Tesla field and with Be foil soon.

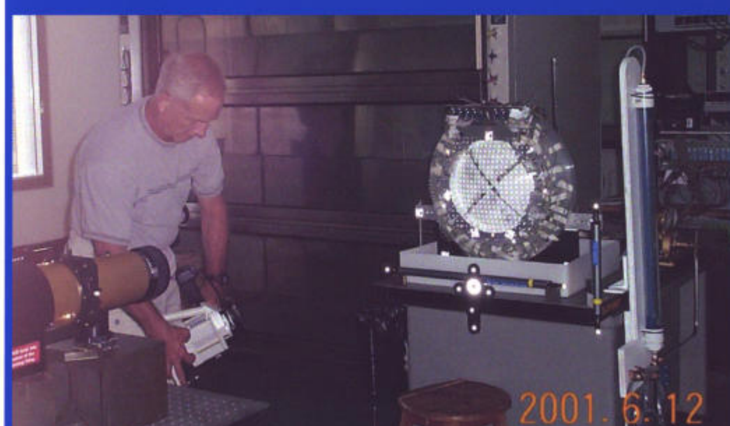
200 MHz cavity (ν factory) >> 17 MV/m being designed >> high power tests in ~ 2 years

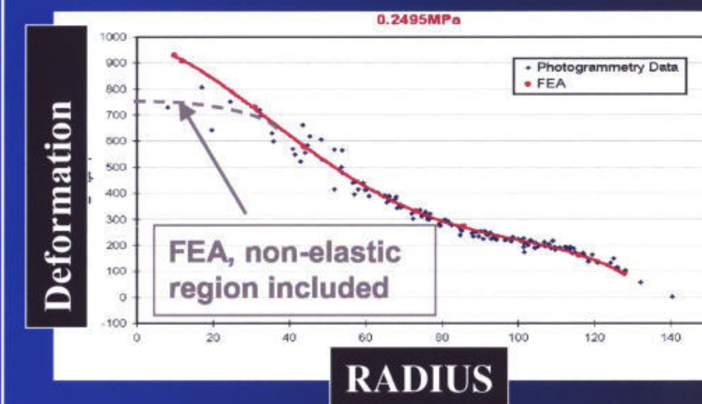
MUCOOL Liquid H2 Absorber R&D - 1

Need thin windows to minimize scattering

330 µm windows made (Mississippi) & measured (FNAL)

Pressure tests performed (NIU) on 4 Windows including one at LN2 temp.





FEA calculations give a good description observed window deformation and rupture

MUCOOL Liquid H2 Absorber R&D - 2

Must remove O(100) W heat deposited by dE/dx >> good radial mixing

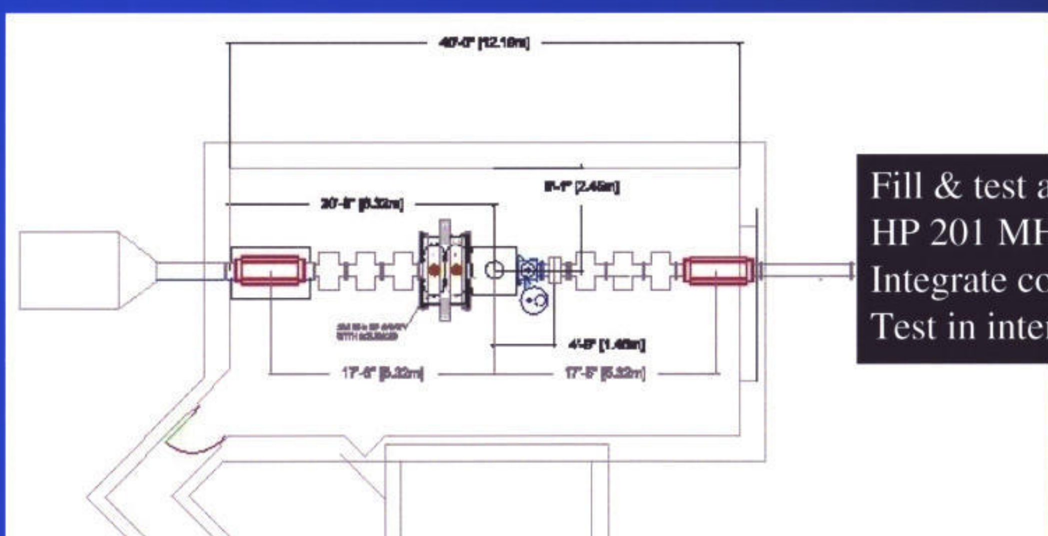
TWO CONCEPTS

1. **Forced flow through nozzles:**
   - → Prototype being built by University consortium
   - → Flow pattern under study

2. **Driven convection:**
   - → Prototype being built by KEK & Osaka
   - → Tested with Liq. Neon and heat deposited with wire array (low power) suggests 100W cooling OK
   - → 100W test planned

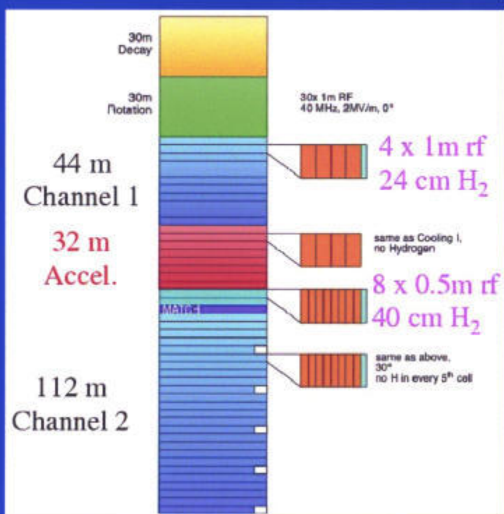
Both absorbers will be filled with Liq. H2 and tested at Fermilab

New MUCOOL Test Facility



Fill & test absorbers
HP 201 MHz (& 805 MHz ?) Tests
Integrate components into a unit
Test in intense ionizing beam

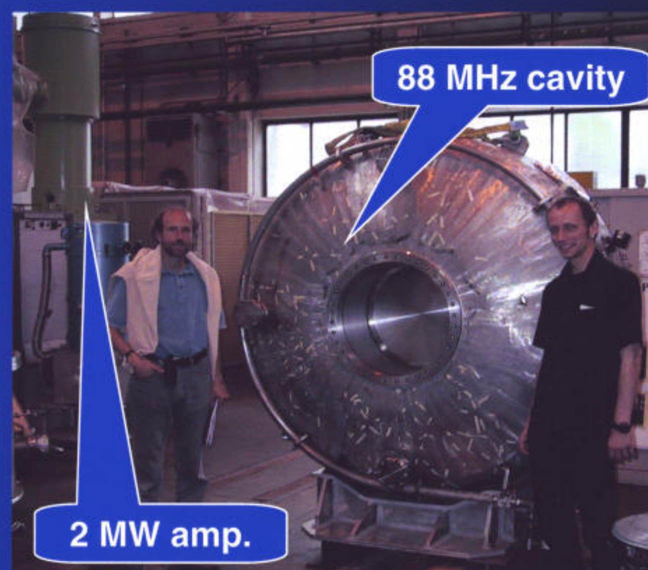
CERN Phase Rotation & Cooling



No Induction Linac – use drift + 44 MHz cavities for the phase rotation

Cooling channel based on 44 MHz & 88 MHz cavities with some acceleration in middle

	Channel 1	Channel 2
Length	46 m	112 m
Diameter	60 cm	30 cm
Solenoid B	2.0 T	2.6 T
RF Freq.	44 Mhz	88 Mhz
RF Gradient	2 MV/m	4 MV/m
Beam Energy	200 MeV	300 MeV

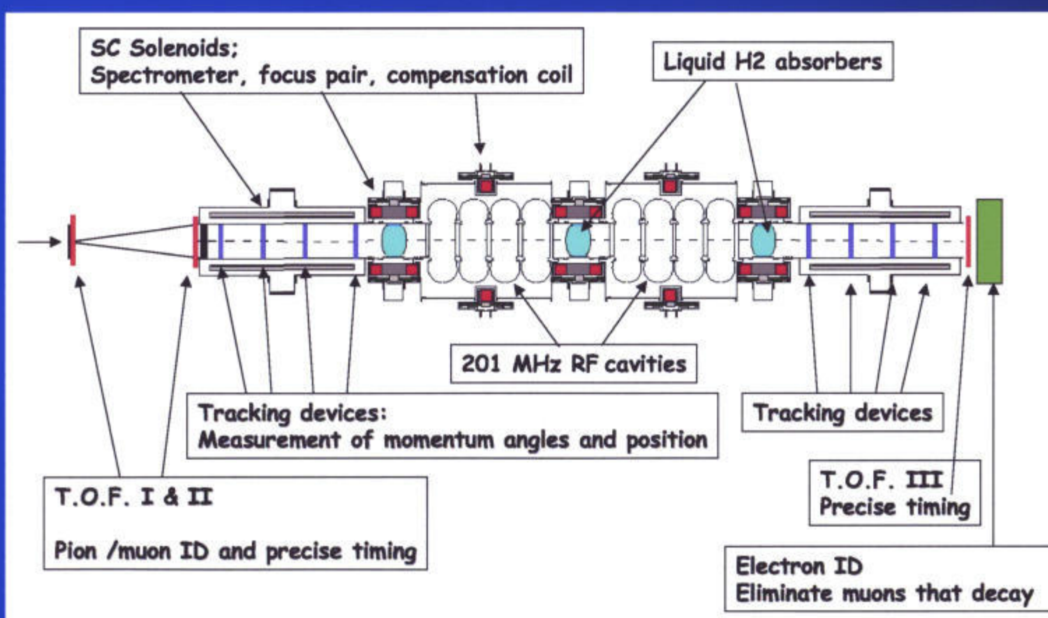


88 MHz High Power test at CERN this year

Cooling Experiment – MICE

LOI for an International Cooling Experiment presented at PSI and Rutherford Lab

Rutherford Lab has put in place a project team



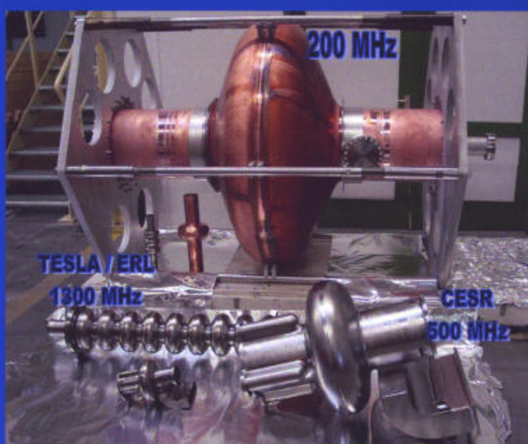
Single particle concept developed (most recently) at CERN.

World Wide effort now in progress to produce a proposal towards the end of this year.

Interested in collaborating ?

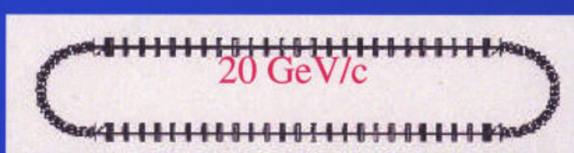
US: D. Kaplan
Europe: A. Blondel
Japan: Y. Kuno

Muon Acceleration & Storage Ring



After cooling, early acceleration with Linac, Later acceleration with RLAs

SC 200 MHz cavity (Niobium sputtered on Copper) being built at CERN for tests at Cornell → 15 MV/m



Japanese Version

1.E20 useful muon decays / year

Everyone has a muon storage ring design; they come in various shapes, but all have long straight sections

Conclusions

- Very active ν-Factory design & component prototyping in Europe, US, & Japan
- US studies have shown ν-Factory feasible after a few years of R&D
- CERN & Japanese studies show alternative technology choices may be promising … must be pursued until we are ready to make a choice
- Much interest in World-Wide collaboration in critical R&D areas …. but will need additional support !
- R&D pursued by Lab and University physicists … particle physicists & accelerator physicists.